

LIFE HISTORY PARAMETERS OF COMMON SOUTHERN CALIFORNIA MARINE FISHES

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Preface

The California Energy Commission's Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

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Life History Parameters of Common Southern California Marine Fish Subject to Entrainment is the final report for Contract Number 500-04-025 conducted by MBC Applied Environmental Sciences. The information from this project contributes to PIER's Energy-Related Environmental Research Program.

For more information about the PIER Program, please visit the Energy Commission's website at www.energy.ca.gov/research/.

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Abstract

Life history parameters are required to complete nearly any mathematical model of a fish population in which limited or no general population estimates are available. In California, most coastal fish species suffer the dual problem of little to no characterizations of their vital rates and no population estimates, especially for open coastal systems. To partially address these shortcomings, this study documented some of the life history parameters for a few of California's common nearshore marine fish, specifically: queenfish (*Seriphus politus*), white croaker (*Genyonemus lineatus*), spotfin croaker (*Roncador stearnsii*), and yellowfin croaker (*Umbrina roncadore*). Adult age and growth was described for queenfish and yellowfin croaker. von Bertalanffy parameters for queenfish were: $L_{\infty} = 181.12$, $k = 0.27$, $t_0 = -1.408$, and $n = 821$, and the parameters for yellowfin croaker were: $L_{\infty} = 307.754$, $k = 0.278$, $t_0 = -0.995$, and $n = 1209$. In both species, females grew significantly faster than males. Spawning seasonality was described for yellowfin croaker. Spawning began by June, peaked in July, and was completed by September, based on histological analysis of males and females. Gonosomatic indices confirmed this periodicity. The identification of a regressing male collected in September further confirmed the termination of spawning. Batch fecundity was calculated for spotfin croaker and yellowfin croaker. Ovaries from female spotfin croaker with a gonosomatic index $> 3.0\%$ were examined. Yellowfin croaker females with a gonosomatic index $> 3.5\%$ were analyzed. Fecundity was regressed against both length (SL mm) and total body weight (g) for both species. Spotfin croaker batch fecundity ($n = 13$) was best described by the equations: $BF = 2E-07SL^{5.0109}$ ($R^2 = 0.79$) and $BF = 13.511Wt^{1.6032}$ ($R^2 = 0.85$). The equations $BF = 2.4SL^{2.0}$ ($R^2 = 0.45$) and $BF = 3300W^{0.68}$ ($R^2 = 0.49$) best described yellowfin croaker batch fecundity ($n = 16$). For both species, total body weight was a better predictor of batch fecundity than was standard length. Daily growth rates for larval queenfish ($n = 122$), spotfin croaker ($n = 100$), and white croaker ($n = 48$) were determined through otolith analysis. Spotfin croaker grew faster in the summer months while no seasonality was detected in queenfish. White croaker seasonality was not examined. The overall growth rates for each of the three species were described by the functions: $L = 0.825age^{0.647}$ ($R^2 = 0.76$) for queenfish, $L = 0.5489age^{0.7316}$ ($R^2 = 0.79$) for spotfin croaker, and $L = -0.833 + 0.424age$ ($R^2 = 0.84$) for white croaker.

Keywords: Life history, age and growth, queenfish, white croaker, yellowfin croaker, spotfin croaker, batch fecundity, and larval growth

Executive Summary

Introduction

The assessment of the effect of once through cooling on fish populations can be very problematic, especially that of the larval life stages. While assessment of impingement impacts can easily be determined through monitoring, assessment of entrainment impacts presents special challenges. These challenges include the fact that entrained organisms, which include fish and invertebrate larvae, are difficult not only to sample, but also to identify. Furthermore, while the estimated larval entrainment by a power plant may number in the millions, and sometimes billions, these numbers can give a false impression of the magnitude of effects on the adult populations. A million or more larvae of a single species lost through entrainment may only represent the loss of a few adults to the population, especially those species with high reproductive rates, such as the northern anchovy (*Engraulis mordax*). Proper representation of these data requires knowledge of their life stage dynamics, such as growth rate, spawning frequency, etc.

Purpose

The natural ecology, life history, and population dynamics of marine fishes, including a natural larval mortality rate exceeding 99% for most fishes, necessitates the use of mathematical models to accurately represent their importance to the community. The proper evaluation of these losses, including quantifying and place them in their proper ecological context requires the use of mathematical models to convert abstract values (e.g. millions of larvae) into more meaningful metrics (e.g. numbers of adult fish) in order to avoid erroneous, exaggerated impact conclusions. Several such models are used in power plant entrainment studies. These models take into account different factors, such as growth rates, age at maturity, fecundity (reproductive rate), and size structure of the population. With this information, researchers can use larval abundance data in such models to estimate the number of adult fish lost due to power plant entrainment. The use of these models, however, is severely limited by a lack of information on the life history (lifecycle) of key species. Unfortunately, these parameters have been described for only a handful of California's marine species. Most of these descriptions involve species with commercial value, such as the northern anchovy. To fully evaluate the interaction between the operation of a once-through cooling system and the fish found in the region, these data gaps must be addressed.

This study was designed to fill in some of these knowledge gaps and to allow more rigorous modeling of these species. Specifically, the study aimed to characterize some of the life history parameters of queenfish (*Seriphus politus*), white croaker (*Genyonemus lineatus*), spotfin croaker (*Roncador stearnsii*), and yellowfin croaker (*Umbrina roncadore*). All four species are commonly found in power plant entrainment and impingement studies in Southern California, with queenfish and white croaker consistently ranking among the most abundant recorded.

Project Approach

Much of the life history information needed for fish species is archived in their otolith, or ear bone. Typically, every day a new layer of material is deposited over the entire surface of the otolith. This regular deposition, similar to a tree ring, allows researchers to determine the age of that particular fish at the time it was sampled. The knowledge of a fish's age can provide profound insight on its own. Knowing parameters such as longevity and age class abundance can lead to calculation of mortality rates for that species. When coupled with other data—such as length, weight, and sex—how fast a species grows can be determined, when it generally reaches sexual maturity, and the age structure of the population or fishery landings.

Analysis of the reproductive organs of these fish will tell what time of year the species will spawn, the length of the spawning season, female spawning frequency in one season, the number of eggs a female can produce at one time (batch fecundity), the variation in egg production with age and size, the potential or occurrence of sex change in the species during its lifetime, and the presence of any social structure to the spawning, such as males controlling a harem of females, as occurs in the California sheephead (*Semicossyphus pulcher*). When this is combined with information gleaned from standard length and weight measurements as well as information from the otolith evaluation, the total lifetime fecundity, among other traits, can be determined.

Although some of the aforementioned parameters may not be directly used, they are required to estimate other parameters, such as mortality. These derived parameters, as well as those directly observed, feed into the models used by fishery biologists to assess impingement and entrainment assessments. From this data, the age-at-length, mortality (survival), annual fecundity (eggs produced per year), total lifetime fecundity (eggs produced over female's lifetime), age at first maturity, and total lifespan could be either directly observed or calculated. These represent the majority of all the parameters required for models commonly used in power plant entrainment assessments.

Project Outcomes

Adult age and annual growth rates of adult queenfish and yellowfin using otolith analysis are described in this study. The maximum observed ages in this study were 15 years for yellowfin croaker and 12 years for queenfish. These two fish species exhibit growth patterns consistent with most Southern California nearshore fish, rapid growth through the early years before slowing down. Analysis in both species specifically indicated growth was fastest in the late summer and fall, beginning with the end of their summer reproductive period.

Larval daily growth rates were determined for queenfish, spotfin croaker, and white croaker and all three species exhibited gradually declining growth with age. Spotfin croaker displayed significantly greater growth rates during the summer, most likely due to the warmer water temperatures.

The spawning season was determined for the yellowfin croaker based on histological (microscopic) examination of the gonads (sexual reproduction organs). This analysis indicated

yellowfin croaker spawning began by June, peaked in July, and was complete by September. This data is consistent of the spawning seasonality of related species in Southern California, including queenfish and white croaker. Egg production was documented for spotfin and yellowfin croakers and was found to rapidly increase with increasing size, length, and weight of the fish.

This study makes several recommendations for additional studies needed to improve power plant entrainment impact assessments in Southern California. These recommendations are intended to identify whether fish populations affected by once-through cooling technology are following similar or different trends than those not affected by this cooling technology.

Note: All tables, figures, and photos in this report were produced by the authors, unless otherwise noted.

1.0 Introduction

1.1. Background

Life history parameters of nearshore marine fishes have proven critical in not only the authors' understanding of fish species, but also for their proper management. Typically, commercial species population estimates and power plant entrainment/impingement impact analyses were based on demographic models (Adult Equivalent Loss [AEL] and Fecundity Hindcasting [FH]) incorporating multiple life history parameters, such as maximum age, size (age) at maturity, fecundity (annual or total lifetime), growth rate (adult or larval), stage-specific mortality/survival rate, and spawning seasonality (Goodyear 1978; Parker 1980; Jensen et al. 1982; Saila et al. 1997; Lo et al. 2005; Newbold and Iovanna 2007). Sufficient research effort into these parameters has been generally limited to commercially important species, such as northern anchovy (*Engraulis mordax*) and Pacific sardine (*Sardinops sagax*) (Hunter and Macewicz 1980; Butler et al. 1993; Lo et al. 1995; Butler et al. 1996; Lo and Macewicz 2005). Substantially less information is available for recreational and forage species. See <http://www.dfg.ca.gov/marine/lifehistory.asp>.

Recent once-through cooling entrainment assessments have been hindered by the aforementioned lack of life history information (Steinbeck et al. 2007). This lack of basal parameters has removed nearly all of the demographic models from consideration in these assessments, thereby limiting the analysis to proportional models, such as the Empirical Transport Model (ETM) (Boreman et al 1981; MacCall et al. 1983). The ETM relies on simultaneous source water population estimates and entrainment estimates. From these estimates, a proportional mortality is calculated. While free from the restrictions of the AEL or FH, the ETM suffers its own limitations, namely the presence of the chosen taxa in both entrainment and source water samples from the same survey. Due to the patchy nature of ichthyoplankton assemblages, and the prevailing current patterns that significantly contribute to their distribution, an assemblage sampled one hour may not be in the area the next (Pepin 2002), making the time between source water sampling and entrainment sampling of significant importance for considering the ETM.

Problems with entrainment assessment become most glaring in those instances when insufficient data were available for either suite of models, demographic or ETM. As an example, six taxa comprised greater than 80% of all entrained fish larvae in the entrainment analysis for Huntington Beach Generating Station (MBC and Tenera 2005). Of these six, only the three-species complex goby CIQ (*Clevelandia ios*, *Ilypnus gilberti*, and *Quiatula y-cuada*), also known as goby A/C, and northern anchovy had sufficient life history information available and same-survey collections to allow both model types to be used. Two of the remaining four species could not be evaluated using any of the aforementioned models. Spotfin croaker (*Roncador stearnsii*) and salema (*Xenistius californiensis*) exhibited highly patchy distributions with individuals collected only during entrainment surveys without source water collections, and little to no available

life history information. The remaining species were sufficiently distributed among entrainment and source water samples to allow for ETM modeling, but the lack of life history parameters precluded the use of demographic models.

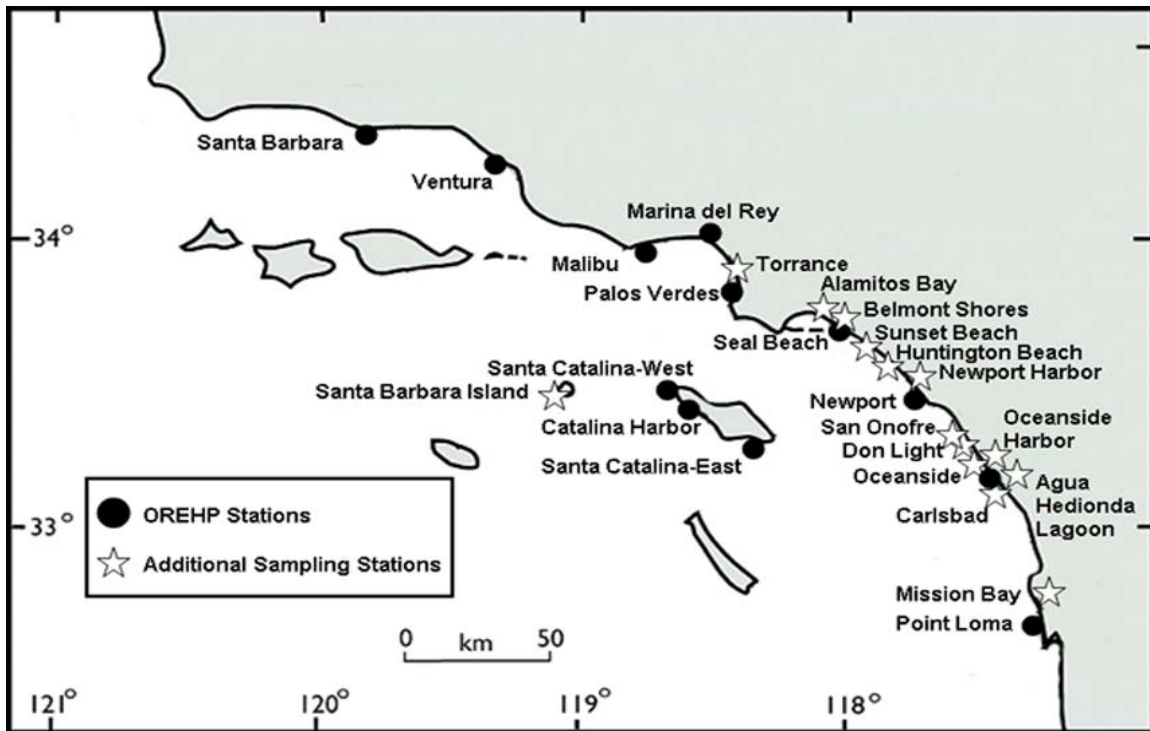
Results from the Huntington Beach L.L.C. Generating Station entrainment and impingement study (MBC and Tenera 2005) were reviewed and the relevant taxa selected based on their relative abundance in this assessment, life history parameters needed, and availability of suitable samples. Based on this evaluation, the following juvenile/adult and larval parameters were selected, by species:

- Queenfish (*Seriphus politus*)
 - Larval daily growth rate
 - Juvenile/adult growth rate
- Yellowfin croaker (*Umbrina roncadore*)
 - Juvenile/adult growth rate
 - Adult batch fecundity
 - Adult spawning seasonality
- Spotfin croaker (*Roncadore stearnsii*)
 - Larval daily growth rate
 - Adult batch fecundity
- White croaker (*Genyonemus lineatus*)
 - Larval daily growth rate

The existing life history literature for these varied considerably, by species. The life history dynamics of white croaker and queenfish were the most documented. Literature regarding queenfish was largely restricted to reproductive dynamics (Goldberg 1976; DeMartini and Fountain 1981; DeMartini et al. 1985) but lack any age and growth dynamics. The literature regarding white croaker life history was more robust with assessments of reproductive biology and age and growth (Goldberg 1976; Love et al. 1984). Spotfin croaker and yellowfin croaker, however, have been largely understudied with regards to life history dynamics. Otolith-based information on age and growth, at any stage, and reproductive biology were missing from the primary literature for both species, although Love (1991) reports on anecdotal information concerning each species. Overall, larval dynamics for most nearshore California fishes were largely undocumented. The current study was designed to address some of these species-specific life history data gaps.

2.0 Project Approach

Samples for each study component were collected through a variety of sampling methods at different sites, including gillnet surveys throughout much of the Southern California Bight, power plant impingement surveys, offshore otter trawls, beach seine surveys, and offshore ichthyoplankton surveys. Yellowfin croaker for the adult age and growth study were collected from a wider variety of stations (Figure 1) than the remaining study components (Figure 2). Each component is further detailed, including collection method below.



Source: Pondella et al. 2008

Figure 1. Ocean Resource Enhancement and Hatchery Program (OREHP) and additional collection sites for yellowfin croaker adult age and growth samples.

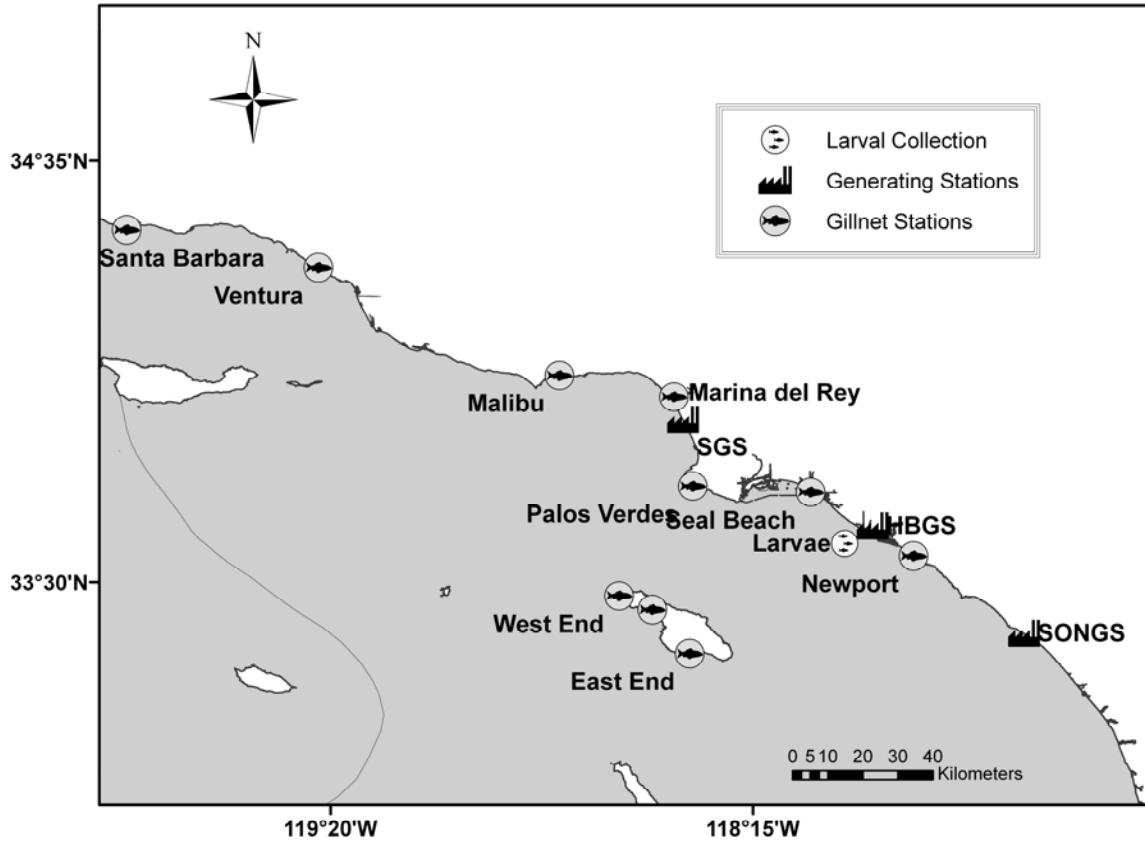


Figure 2. Sample collection sites for all study components other than yellowfin croaker adult age and growth.

2.1. Adult Age and Growth

Adult yellowfin croakers used for age and growth analysis were collected during the Ocean Resources Enhancement and Hatchery Program (OREHP) gillnet monitoring surveys from June 2003 through August 2004 (Figure 1). A total of seven stations were occupied along the coast, ranging from Newport to Santa Barbara, and three additional stations at Santa Catalina Island. All stations were occupied in June, August, and October 2003 and again in April, June, and August 2004. During each sampling event, six replicate monofilament gill nets, each 45.7 m in total length and 2.4 m in depth, each consisting of six, 7.62 m long panels (two each of 25.4, 38.2, and 50.8-mm square mesh) were deployed on the bottom in the late afternoon and retrieved the following morning. Nets were set in 5-14 m depth on sandy bottom usually just outside the surf zone and either close to kelp beds or on the fringe of rocky reefs. The exceptions to this protocol were Marina del Rey and Seal Beach, which do not have rocky reefs or kelp beds. Marina del Rey is part of the Ballona Wetland system, but has been converted to a small craft marina. As such, nets were set out of the boating lanes in two locations. Three were set parallel to the riprap between the U.S. Coast Guard and UCLA docks, and three were set in Mother's Beach. At Seal Beach the nets were set along the eastern stretch outside the surf zone on the sand near the west jetty, which borders the entrance to the Anaheim

Bay and Huntington Harbor part of the Bolsa Chica wetlands. During the 2003-2004 OREHP sampling seasons, sagittal otoliths were collected from 866 yellowfin croaker. An additional 21 individuals were collected in beach seines, and three individuals were collected on hook and line from 13 sites along the coast ranging from Torrance to Mission Bay, and one site at Santa Barbara Island (Pondella et al. 2008). An additional 319 samples from size classes that were underrepresented in the ORHEP sampling were provided by the California Department of Fish and Game. These samples were collected from 1994 to 1997 during seine and trawl studies at various sites throughout Southern California. In total, samples were collected from 31 sites located throughout the Southern California Bight.

Samples for the adult queenfish age and growth study were collected during impingement monitoring at Scattergood Generating Station (SGS) in El Segundo, Huntington Beach Generating Station in Huntington Beach (HBGS), and San Onofre Nuclear Generating Station in San Clemente (SONGS) (Figure 2). All samples were collected from May 2006 through March 2007. The length frequency of the age and growth samples was compared to those collected during trawl surveys offshore of Seal Beach and Huntington Beach, 2001-2006, to evaluate how well the impinged assemblage represented offshore populations. A X^2 test was used to compare the two size distributions after both were $\ln(x+1)$ transformed. Individuals smaller than 30 mm SL were not measured in trawl surveys.

All samples, from both species, were measured to the nearest millimeter (mm) standard length (SL), weighed to the nearest gram (g), sexed macroscopically, and the sagittal otoliths were removed. One sagittae from each pair was mounted on a wood block using cyanoacrylate glue. A 0.5-mm transverse section was taken through the focus using a Buehler Isomet® low-speed saw (Allen et al. 1995). Sections were read submerged in water under reflected light with a stereoscope by a single reader consistent with techniques described in Cailliet et al. (1986) and Campana (1992). A minimum of two readings per section was made with a minimum of one month separating each reading. Edge type, either translucent (T) or opaque (O), was recorded for each sample. If no agreement between the two readings occurred, then a third and final reading was made. Annuli formation was confirmed using otolith edge analysis, or the ratio of T:O for each month. Non-linear regression (yellowfin croaker) and VONBIT (Fisheries Department, FAO) (queenfish) were used to fit the age-at-length data to the von Bertalanffy growth model:

$$L_t = L_{\infty} (1 - \exp -k(t-t_0))$$

where

L_t = length at time t

L_{∞} = theoretical maximum length

k = constant expressing the rate of approach to L_{∞}

t_0 = theoretical age at which $L_t = 0$.

Whole sample and sex-specific growth rates were plotted for each species. Differences in the sex-specific growth rates were determined using analysis of residual sum of squares (also known as “extra sum of squares” or “conditional error principle”) derived by non-linear regression (ARSS, Ratkowsky 1983; Craig et al. 1999; Haddon 2001; Pondella et al. 2008; Miller et al. 2008). Immature or sex-undetermined individuals were excluded from sex-specific comparisons for queenfish but included with males and females in the analysis for yellowfin croaker.

2.2. Adult Spawning Seasonality

Adult yellowfin croaker were collected during impingement surveys at SONGS (Figure 2). Individuals were sexed macroscopically, measured to the nearest mm SL, and weighed to the nearest g. Gonads were removed from each, weighed to the nearest 0.5 g, and preserved in 10% buffered formalin. Each gonad sample was dehydrated in an ascending series of ethanol and cleared in toluene. After dehydration, samples were embedded in paraffin, and histological sections were cut at 5 μ m using a rotary microtome. Sections were mounted on glass slides and stained with Harris hematoxylin followed by eosin counterstain. Slides were evaluated to determine the stage of the spermatogenic cycle in males and the ovarian cycle in females. Female stages were in accordance with Goldberg (1981). Stage 1 (regressed or regressing) was the nonspawning condition consisting mainly of primary oocytes. Stage 2 (previtellogenic) consisted of slightly enlarged vacuolated oocytes. Stage 3 (vitellogenic) was characterized by yolk deposition in progress. In Stage 4 (spawning) mature (ripe) oocytes predominate and some postovulatory follicles may be present. Males were characterized as spawning or regressing/inactive.

2.3. Adult Batch Fecundity

Adult yellowfin croaker and spotfin croaker were collected during impingement surveys at SONGS (Figure 2). For yellowfin croaker, a gonosomatic index (GSI) was derived for each individual, with a minimum value of 3.5% for inclusion in the batch fecundity study based on Pondella et al. (2008) and the results of the histological analysis. The GSI was calculated by the equation: $GSI = (\text{gonad weight} / \text{gonad free body weight}) * 100$ (Barbieri et al. 1994). For spotfin croaker, a GSI was derived for each individual as described for yellowfin croaker. A minimum spotfin croaker GSI of 3.0% was required for inclusion in the study. Preliminary GSI data for spotfin croaker indicates peak spawning to occur from June through August with GSI values greater than 3.5% (Vantuna Research Group, unpublished data).

For both species, two sections of approximately 0.5 g of ovarian tissue per ovary were taken from each fish near the posterior and medial areas of each lobe. A minimum of two independent counts of ripe oocytes from each subsample were made under stereomicroscopy. In instances of high variation, sections were recounted. The mean egg count and standard error per 1g ovarian tissue for each individual female was calculated

and later multiplied by the total gonad weight to estimate the individual batch fecundity. Batch fecundity (BF) was regressed against both standard length and total body weight to determine the relationship between both parameters.

2.4. Larval Age and Growth

All larvae were collected offshore of HBGS from December 2003 to September 2004 (Figure 2). Sampling consisted of oblique bongo net tows with 333- μ m mesh nets fitted with calibrated flowmeters. The contents of one net from each deployment were preserved in 4% buffered formalin-seawater while the other net was preserved in 70% ethanol. After survey completion, ethanol samples were archived. Formalin fixed samples were washed and transferred to 70% ethanol for sorting and identification three days after collection.

Larval spotfin croaker samples ($n = 100$) were exclusively taken from ethanol preserved samples. White croaker samples ($n = 48$) were mostly recovered from ethanol samples ($n = 47$) and one from formalin preserved samples. Queenfish samples ($n = 122$) were taken from both ethanol ($n = 74$) and formalin ($n = 48$) preserved samples. After identification (Moser 1996) individuals from each species were measured by capturing digital images through a video stereoscope and processing the image through image analysis: Adobe Photoshop for spotfin croaker and white croaker, SigmaScan Pro 5 for queenfish. Both sagittal otoliths were removed from each individual under stereoscope magnification using reflected light, mounted on a glass slide using immersion oil, and viewed under compound microscopy (400x-1000x magnification) using transmitted, polarized light. Daily growth bands were defined as those regularly spaced, consistently visible across variable focal planes, and formed a nearly continuous band around the otolith, consistent with the descriptions in Campana (1992). The assumed daily bands were counted from the core to the edge. Based on laboratory reared larvae and the assumption that sagittal otolith formation coincides with yolk-sac absorption, Barnett and Sertic (19803) concluded otolith formation occurs at two days post-hatch in queenfish and five days post-hatch in white croaker. Final estimated ages in the current study incorporate these findings by adding the species-specific constant (2 or 5) to each increment count.

Shrinkage due to preservation could not be quantified, so no adjustment to the length was made. Furthermore, the technique utilized for the sample collection and processing was consistent with those used in all recent entrainment characterizations done in the Los Angeles and Orange County areas (http://www.waterboards.ca.gov/rwqcb4/water_issues/programs/power_plants/). Lastly, Peters and McMichael (1987) found no significant effects of shrinkage by preservative type in southern kingfish (*Menticirrhus americanus*) length due to shrinkage.

Data was plotted and a best-fit line was drawn using MS Excel®. Seasonal differences in growth rate for queenfish and spotfin croaker were compared using analysis of residual sum of squares derived by non-linear regression (ARSS, Haddon 2001). This technique

was also used to test differences in derived growth curves based on preservation technique for queenfish collected on September 1, 2004.

Daily mortality estimation for each species was attempted using catch curve analysis, or the linear slope of the natural log of abundance over age class (Haddon 2001).

Individuals were grouped into five-day blocks prior to the catch curve analysis, as per Alvarez and Cotano (2005). These estimates were evaluated against published values to determine their relative accuracy in light of the oblique sampling method, which typically samples the midwater, with only minimal sampling time at either the epibenthos or neuston. Insufficient data on current patterns during the sampling period was available to adjust the mortality estimates based on dispersion out of the sampling area, but to an equally suitable area. Therefore, these estimates are presented with an additional caveat due to this lack of current dispersal adjustment.

3.0 Project Outcomes

3.1. Adult Age and Growth

The results of each adult age and growth study are presented below and in Pondella et al. (2008) and Miller et al. (2009).

3.1.1. *Yellowfin Croaker*

In yellowfin croaker, otolith edge analysis determined 91.6% of the otoliths still had an opaque edge in June, indicating these bands were annuli (Lowerre-Barbieri et al. 1994). The onset of translucent rings began with the summer season, and occurred primarily in the summer and fall, or the peak reproductive period.

Typically, yellowfin croaker were 101 mm SL by their first birthday and 170 mm SL by their second. Growth began to slow in their third year (mean = 188 mm SL) as they became sexually mature. The sex of 50% of the individuals could be macroscopically determined by 150 mm SL and 100% by 200 mm SL. The overall male to female sex ratio (51:49) was not significantly different from a 50:50 ratio ($X^2 = 0.7$; $P > 0.1$) and males and females were found at all sizes. The largest sexed individual was a male of 395 mm SL and the largest female was 365 mm SL. The oldest specimens were 15-year-old males, one caught at Santa Barbara Island (June 13, 2006; 395 mm SL) and another caught at Belmont Shore (February 28, 1995; 313 mm SL). The largest yellowfin croaker (420 mm SL) was caught at Palos Verdes on June 3, 2003. This fish was 7 years old and apparently experienced a faster growth rate than the rest of the studied specimens as many fishes were above the L_{∞} values (Figure 3). The otolith width for this specimen was second only to that of a 15-year old specimen, further confirming the estimated age.

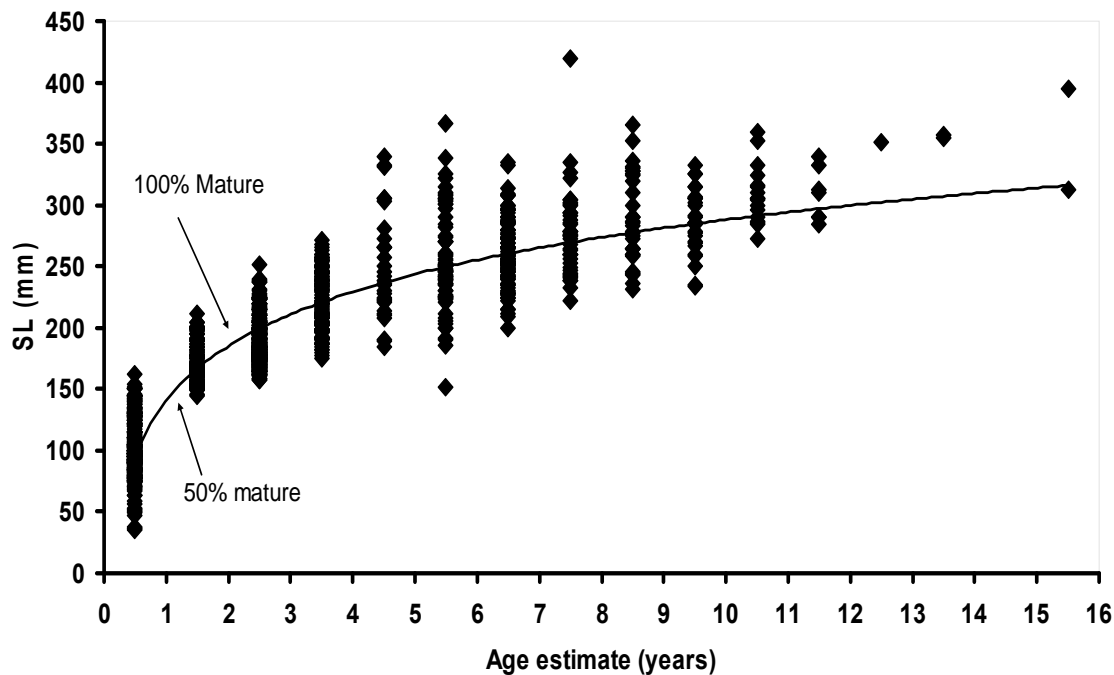


Figure 3. Size (SL) at age for 1209 yellowfin croaker with a fitted von Bertalanffy growth curve. Size at 50% and 100% maturity are noted.

All von Bertalanffy model values were significantly different between the sexes; females grew significantly faster and reached significantly larger size than males at age (L_{∞} : $F_{1,1465} = 4.021$, $p < 0.05$; k : $F_{1,1465} = 4.587$, $p < 0.05$; t : $F_{1,1465} = 15.573$, $p < 0.01$). Growth in length for both sexes began to slow with the onset of gonad development (Figure 3).

Table 1. Output parameters obtained from a statistical fitting to the von Bertalanffy model to standard length for all fish, females plus immature, and males plus immature for each of these three measurements.

(1) Standard Length Estimation		Parameters Estimated		
Group	L_{∞}	k	t_0	
All (n=1209)	307.754	0.278	-0.995	
All females & immature (n=726)	313.173	0.307	-0.771	
All males & immature (n=744)	298.886	0.269	-1.072	

3.1.2. Queenfish

Individuals were collected from May 2006 through March 2007. Annular formation was confirmed through otolith edge analysis. Annuli otolith increment deposition was indicated by a gradual shift from translucent edges to opaque edges from January through June. The proportion of translucent edges again increased from summer through fall, with November exhibiting the same proportion of translucent edges as was

observed in January. No significant differences were detected between the age-at-length and offshore size distributions.

Individuals grew relatively quickly during the first six years of life before slowing (Figure 4). Von Bertalanffy predictions closely fit the observed values. Total sample ($n = 821$) von Bertalanffy parameters were $L_{\infty} = 181.12$, $k = 0.27$, $t_0 = -1.408$. Observed ages for the total sample ranged from less than one year to 12 years old. Females grew to a larger predicted size than males, 198.88 mm SL and 179.88 mm SL, respectively, with females growing at a significantly faster rate than males (ARSS, $F_{1,463} = 16.92$, $p < 0.0001$) (Figure 5). Female von Bertalanffy parameters were $L_{\infty} = 198.88$, $k = 0.17$, $t_0 = -3.146$, $n = 376$ and male parameters were $L_{\infty} = 179.88$, $k = 0.15$, $t_0 = -4.451$, $n = 90$. The remaining 354 individuals were juvenile or sex undetermined. Individuals reached 50% maturity by 100 mm SL (Age 1) and 100% maturity by 130 mm SL (Age 3).

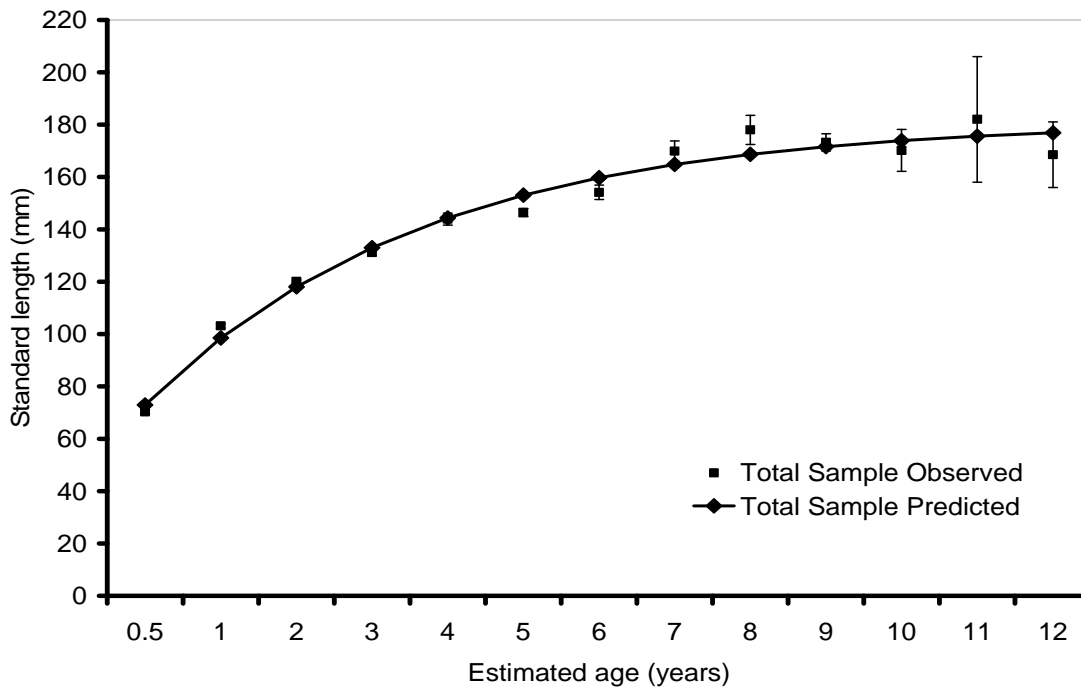


Figure 4. Queenfish observed and von Bertalanffy model predicted age at length (SL mm) for the total sample.

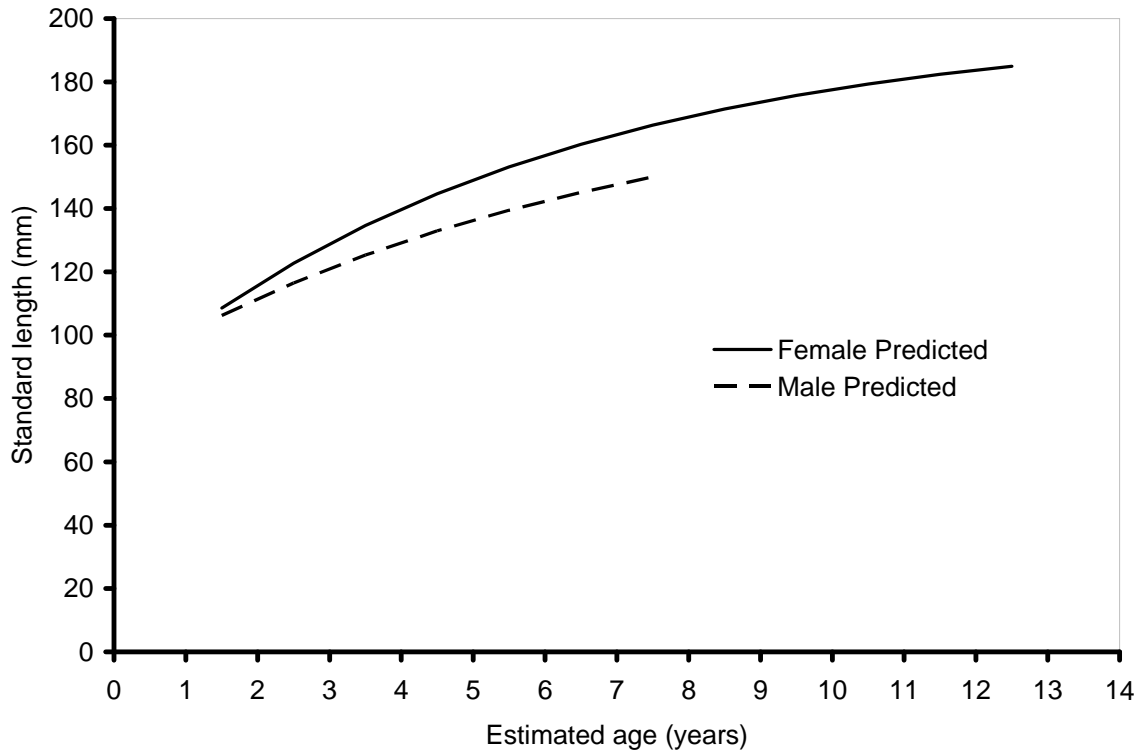


Figure 5. Queenfish observed and von Bertalanffy model predicted age at length (SL mm) by sex.

3.2. Adult Spawning Seasonality

The results of the spawning seasonality study are presented below and in Miller et al. (2009).

3.2.1. Yellowfin Croaker

A total of 86 individuals was collected, 51 female and 35 male, from June 10, 2006 to September 15, 2006. Males ranged from 163 to 309 mm SL, and females from 172 to 340 mm SL. Female mean GSI values were consistently greater than 4.0% in June and July, but declined to approximately 3.5% in August (Figure 6). By September, mean GSI was below 1.0%.

Histological analysis of all individuals suggested peak spawning in July as indicated by high frequency of ripe (Stage 4) and near-ripe (Stage 3) oocytes (Figure 7). Individuals collected in June also showed a substantial proportion (60%) of actively spawning individuals, but 20% of the ovaries examined were dominated by Stage 1 oocytes. No actively spawning females were collected in August, but 28% of the ovaries examined were composed of Stage 3 oocytes. Spawning was complete by September with greater than 90% of all oocytes observed in Stage 1 development. One male with regressing testes was identified from September collections, further indicating a cessation of the spawning season. Evidence of serial spawning was noted, namely the bimodal

distribution of oocytes within individual ovaries, one spawning mode and one vacuolated mode.

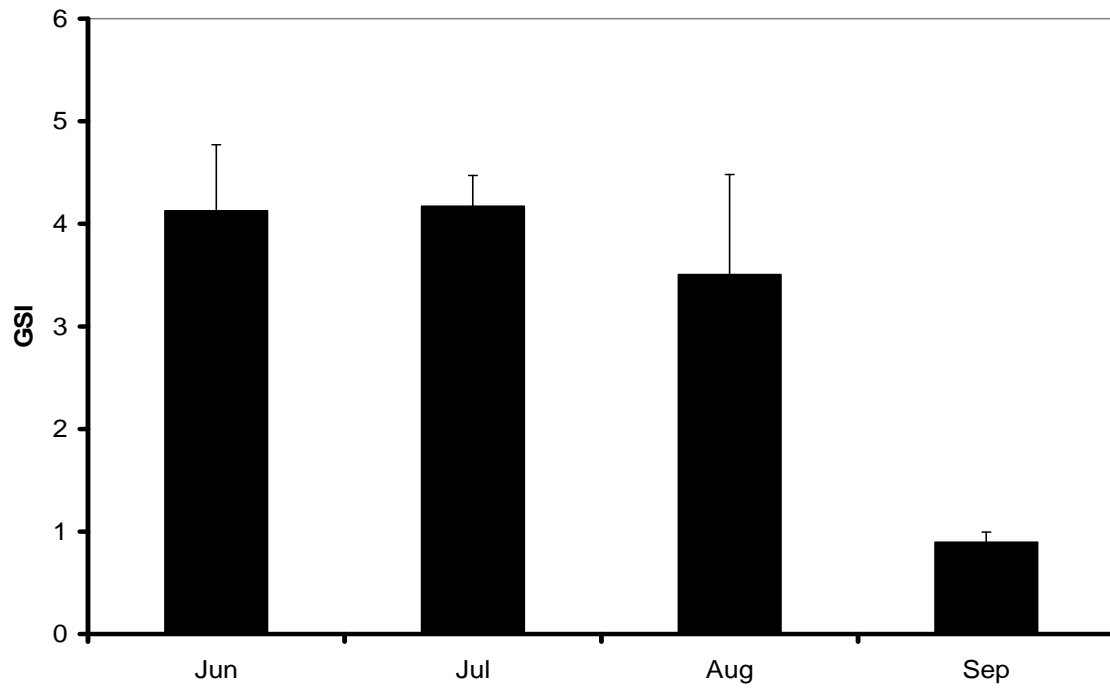


Figure 6. Mean monthly GSI, plus one standard error, for 51 female yellowfin croaker (*Umbrina roncadore*) collected off San Clemente, California, from June through September 2006.

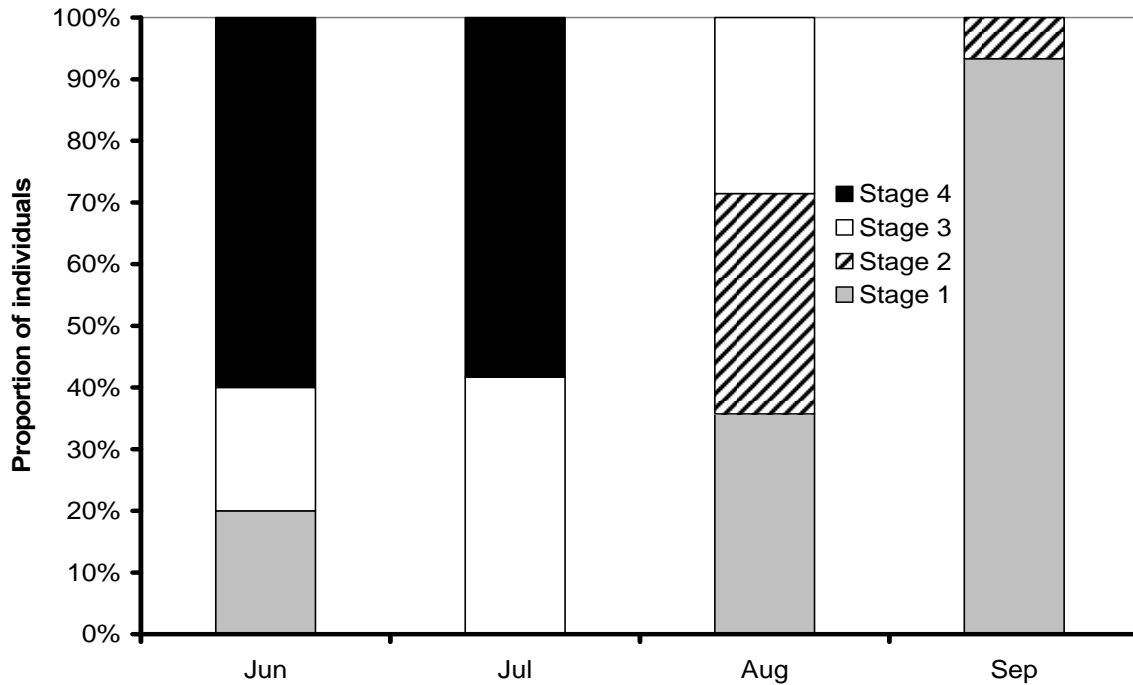


Figure 7. Proportional distribution of ovarian stages by month for 51 female yellowfin croaker (*Umbrina roncadore*) collected from June through September 2006.

3.3. Adult Batch Fecundity

The results of the batch fecundity studies on spotfin croaker and yellowfin croaker are presented below and in Miller et al. (2009).

3.3.1. Spotfin Croaker

A conservative minimum threshold of GSI = 3.0% was set as the criterion for inclusion in the fecundity study, based on preliminary observations of gillnet-collected individuals (Vantuna Research Group, unpublished data). A total of 13 individuals were included in the analysis out of 26 collected. Females ranged in size from 202 to 306 mm SL with gonad weights ranging from 6 to 41 g (Table 2). All collections were made in June 2006, corresponding to the peak GSI level recorded in the gillnet surveys. Batch fecundity increased exponentially with body size (SL) generally following the equation $BF = 2E-07SL^{5.0109}$ ($R^2 = 0.79$) (Figure 8), with individual values ranging from 35,169 to 640,703 (Table 2). Body weight was found to be a better predictor of batch fecundity ($R^2 = 0.85$) following the equation $BF = 13.511Wt^{1.6032}$ (Figure 9).

Table 2. Standard length (mm), total body weight (g), gonad weight (g), GSI, and batch fecundity for 13 female spotfin croaker (*Roncador stearnsi*) used in the study.

SL (mm)	Body Weight (g)	Total Gonad Wt (g)	GSI	Total Batch Fecundity
202	175	6	3.55	35,169
216	242	8	3.42	106,696
216	228	10	4.59	87,790
236	268	14	5.51	124,581
241	316	15	4.98	182,185
242	287	13	4.74	96,889
244	367	25	7.31	290,763
272	450	24	5.63	153,534
280	456	16	3.64	232,152
284	505	25	5.21	318,938
295	655	23	3.64	275,845
302	713	46	6.90	640,703
306	659	41	6.63	480,069

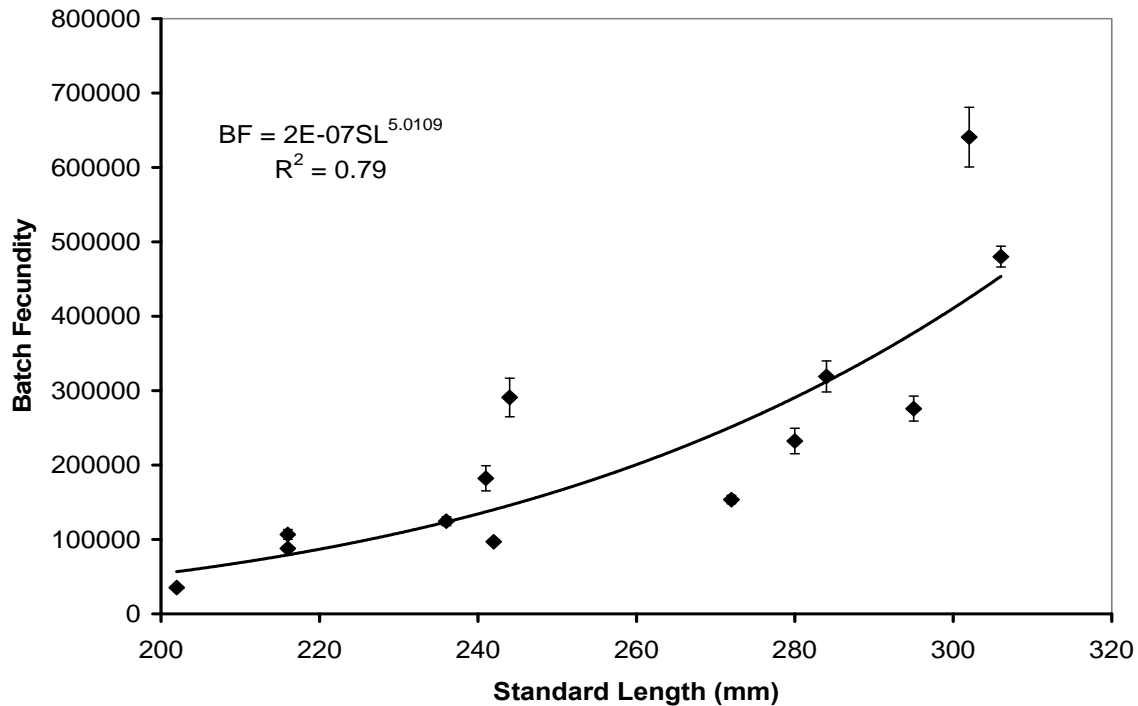


Figure 8. Mean individual batch fecundity by standard length (mm) with standard error for 13 female spotfin croaker.

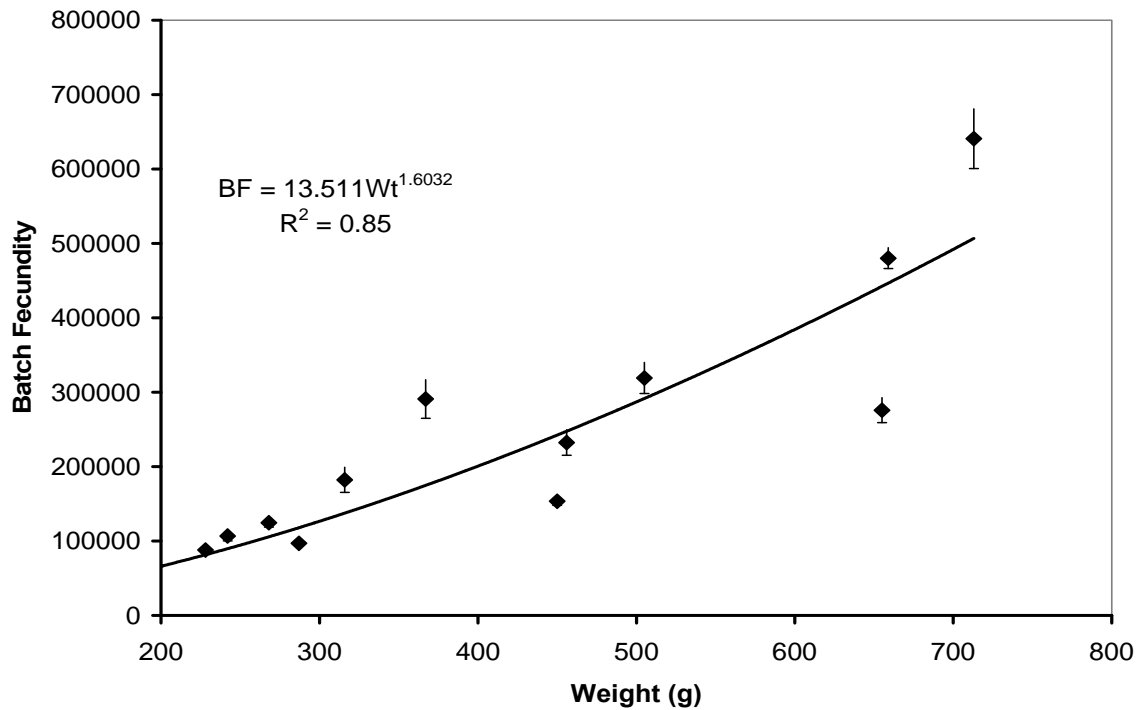


Figure 9. Mean individual batch fecundity by total body weight (g) with standard error for 13 female spotfin croaker.

3.3.2. Yellowfin Croaker

Sixteen females met the criterion for inclusion in the batch fecundity analysis, namely GSI values greater than 3.5%. Batch fecundity ranged from 99,259 to 405,967 ripe oocytes per females ranging in size from 206 mm SL to 313 mm SL (Table 3). Standard length generally predicted batch fecundity ($R^2 = 0.45$) as described by the equation $BF = 2.4SL^{2.0}$ (Figure 10). The relationship between total body weight and batch fecundity was similarly close ($R^2 = 0.49$) as described by the equation $BF = 3300W^{0.68}$ (Figure 11). As was found in spotfin croaker, total body weight was a better predictor of batch fecundity than length.

Table 3. Standard length (mm), total body weight (g), gonad weight (g), GSI, and batch fecundity for 16 female yellowfin croaker used in the study collected in 2006.

SL (mm)	Body Weight (g)	Total Gonad Wt (g)	GSI	Total Batch Fecundity
206	184	10.0	5.75	140,237
206	182	8.0	4.60	99,259
220	276	12.0	4.55	169,884
233	294	17.0	6.14	181,515
243	274	12.0	4.58	126,984
254	348	19.0	5.78	171,352
267	424	17.0	4.18	181,747
269	446	23.0	5.44	234,951
269	410	16.0	4.06	137,360
280	518	18.0	3.60	148,770
283	487	23.0	4.96	223,000
290	583	22.0	3.92	185,321
291	577	28.0	5.10	217,952
308	638	23.0	3.74	186,806
310	691	38.0	5.82	405,967
313	696	26.0	3.88	261,794

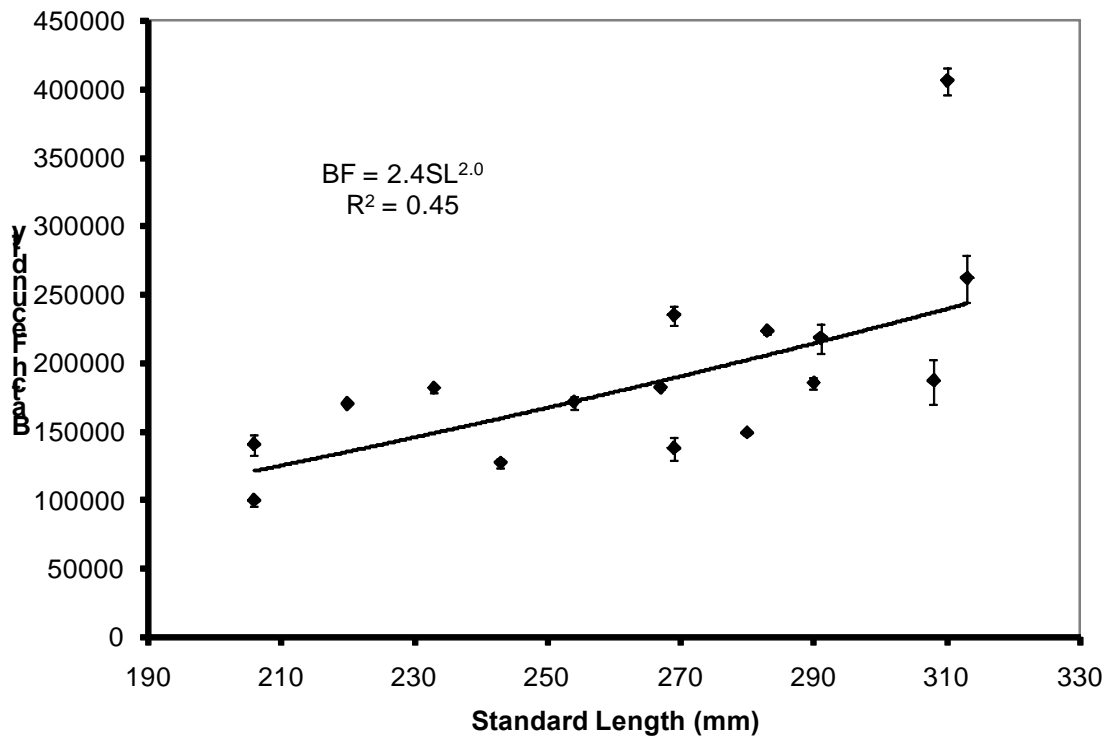


Figure 10. Mean individual batch fecundity by standard length (mm) with standard error for 16 female yellowfin croaker.

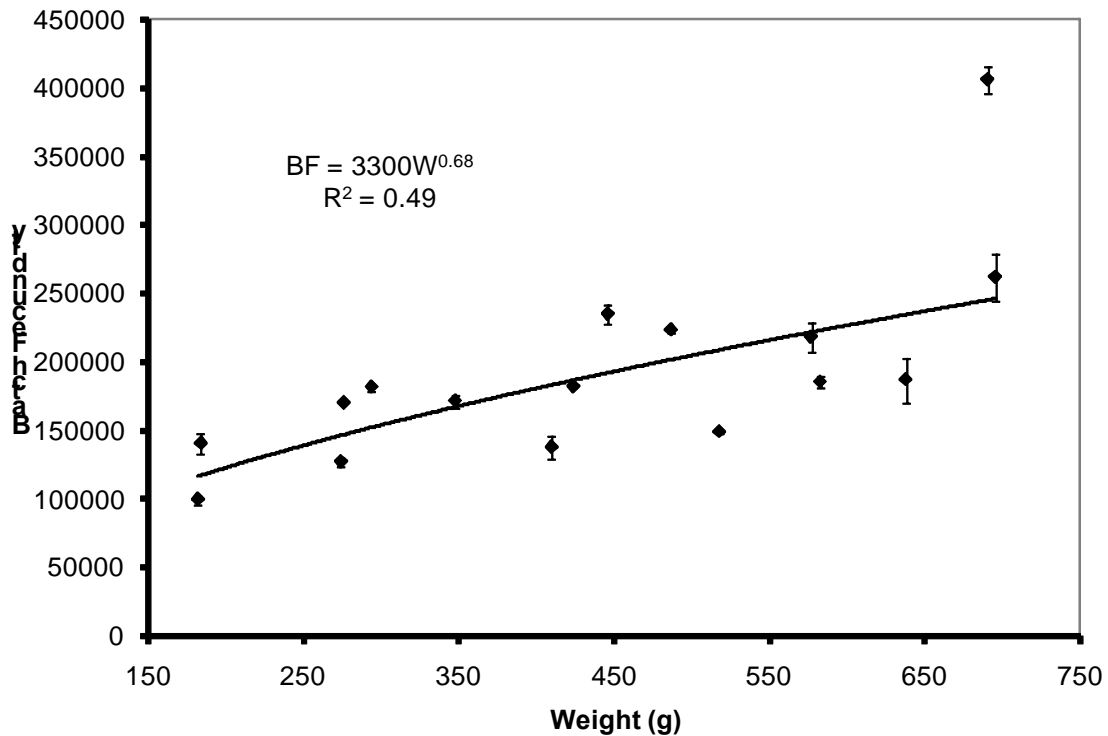


Figure 11. Mean individual batch fecundity by total body weight (g) with standard error for 16 female yellowfin croaker.

3.4. Larval Age and Growth

The results of the larval age and growth studies on queenfish and white croaker are presented below and in Miller et al. (in press).

3.4.1. Queenfish

Larval queenfish growth rate was best described by the power function: $L = 0.825age^{0.647}$ ($R^2 = 0.76$), indicating a variable growth rate by stage, specifically faster growth during the earlier stages before slowing in the later stages (Figure 12). No effect of seasonality in the growth rates was detected (ARSS, $F_{1,114} = 1.82$, $p = 0.17$) No significant difference in growth rates based on preservative type was detected among August-hatched larvae (ARSS, $F_{1,118} = 2.42$, $p = 0.10$) (Figure 13).

Catch curve analysis, or the decline of natural log transformed abundance over time, estimated the total daily larval queenfish mortality at $M = 0.01446$ ($S = 0.9856$), based on the oblique sampling (Table 4). A specific break in the estimated mortality rate was observed between 30- ($M = 0.00998$) and 35-day old individuals ($M = 0.01386$). No adjustments to mortality estimation were made based on current dispersion.

Table 4. Larval queenfish daily instantaneous mortality (M) and survival (S) coefficients by time period, total larval period, 0-30 days, greater than 35 days.

Period	M	S
Total	0.01446	0.9856
0-30 day	0.00998	0.9900
35+ day	0.01386	0.9862

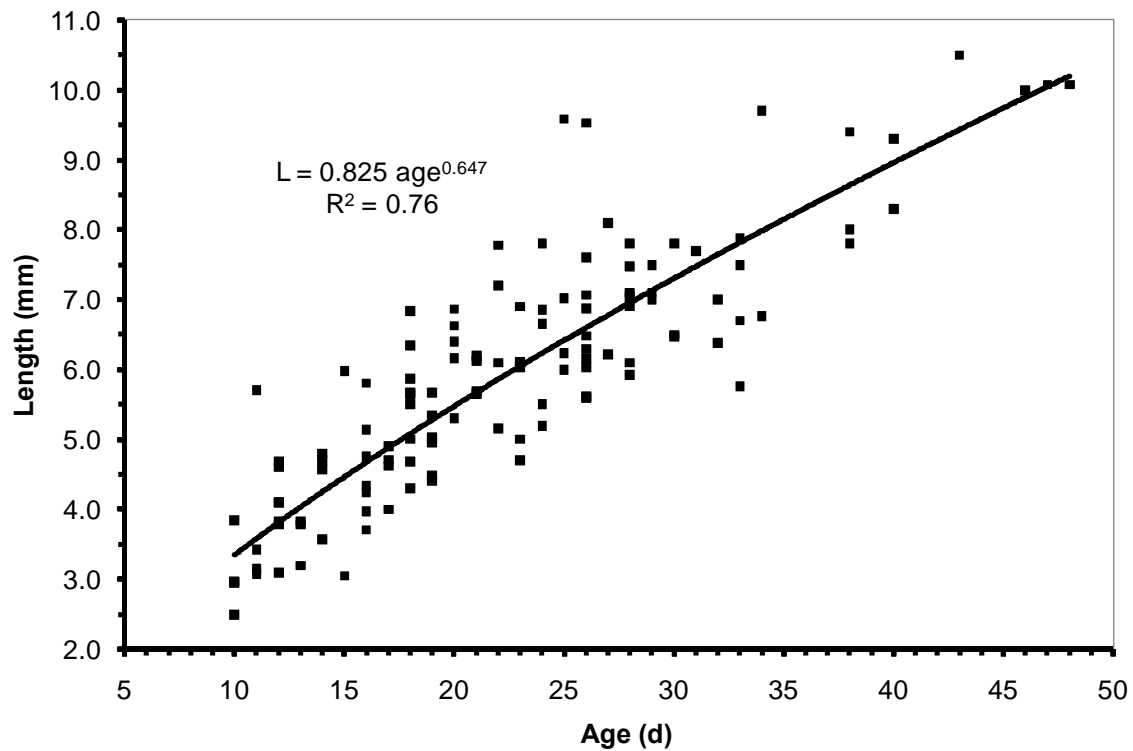


Figure 12. Daily growth of larval queenfish (n = 122) collected offshore of Huntington Beach, California, May 4 – September 1, 2004.

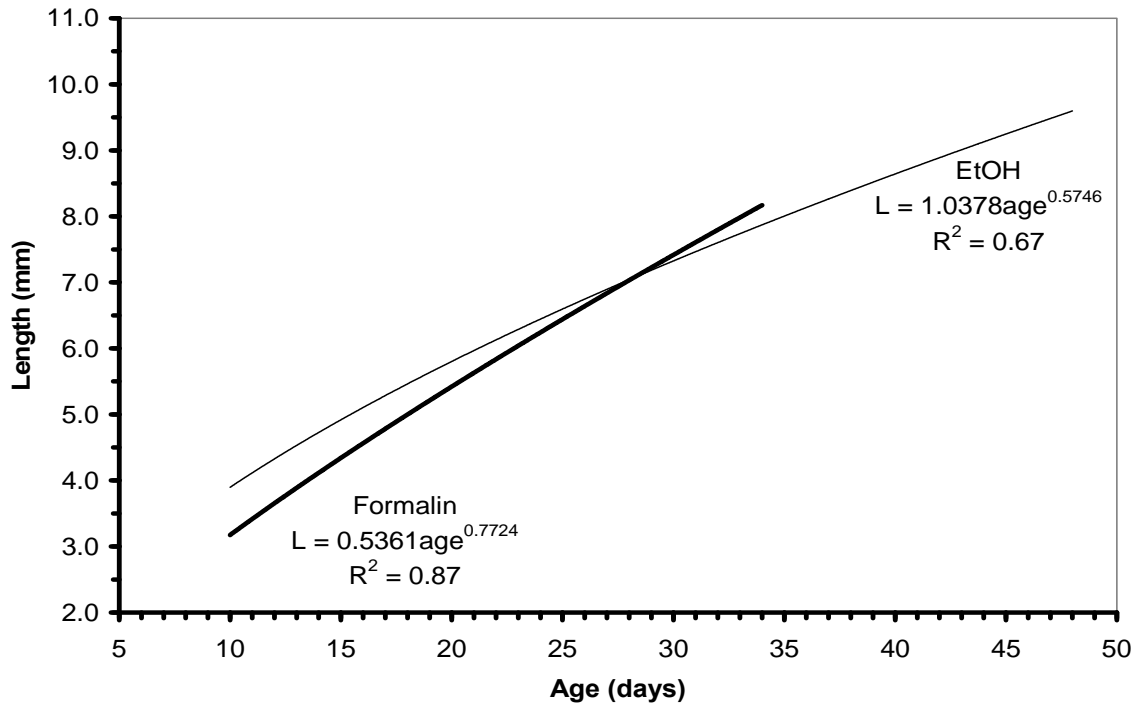


Figure 13. Daily growth rate for larval queenfish (n = 90) by preservative type, 4% buffered formalin-seawater (Formalin) and 90% denatured ethanol (EtOH), for individuals collected offshore of Huntington Beach, California, on September 1, 2004.

3.4.2. Spotfin Croaker

Larval spotfin croaker grew at a gradually declining rate described by the power function $L = 0.5489age^{0.7316}$ ($R^2 = 0.79$) (Figure 14). The growth rate of those larvae hatched before July was significantly lower than those hatched after June 30 (ARSS, $F_{1,99} = 2091$, $p < 0.001$) (Figure 16). Larvae hatching before July were described by the equation $L = 0.6341age^{0.6431}$ ($R^2 = 0.90$) with the post-June cohort growth described by the equation $L = 0.4178age^{0.85}$ ($R^2 = 0.83$) (Figure 15).

Estimated daily mortality (M), unadjusted for dispersal, across all larval stages was 0.0287. There was, however, a definitive shift in mortality at 15 days with the early larval stage mortality ($M = 0.0837$) exceeded by the late larval stage mortality ($M = 0.1313$) based on samples collected by oblique tows.

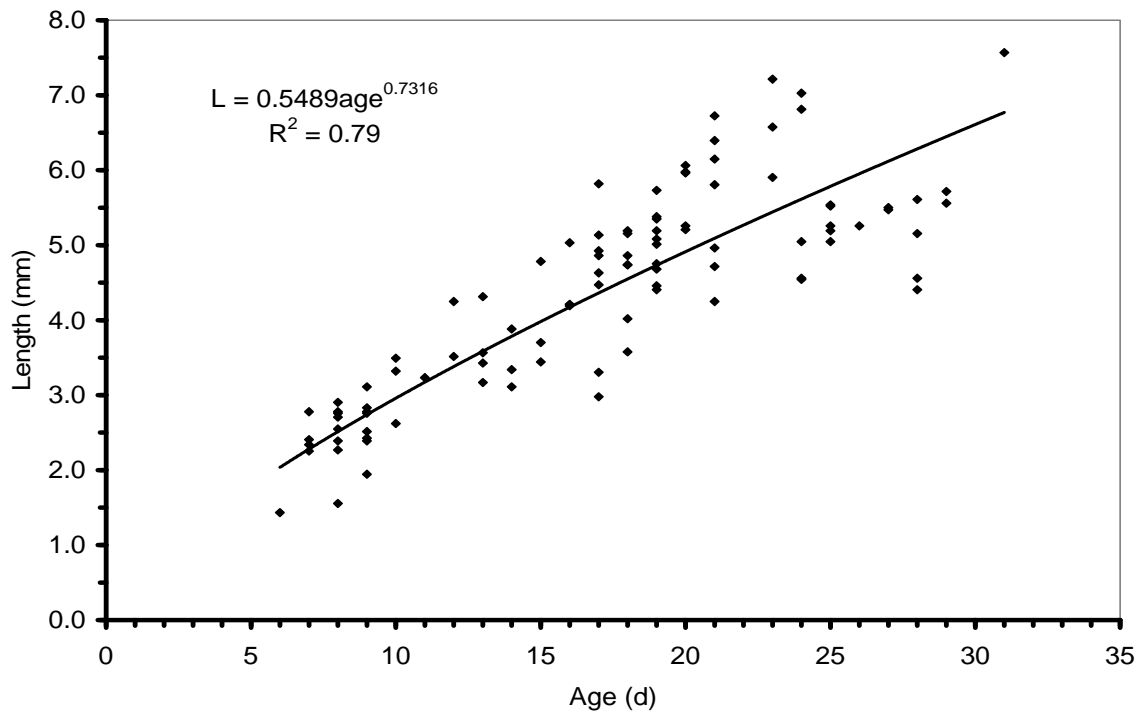


Figure 14. Daily growth for spotfin croaker larvae (n = 100) collected offshore of Huntington Beach, California, between April 7 and August 28, 2004.

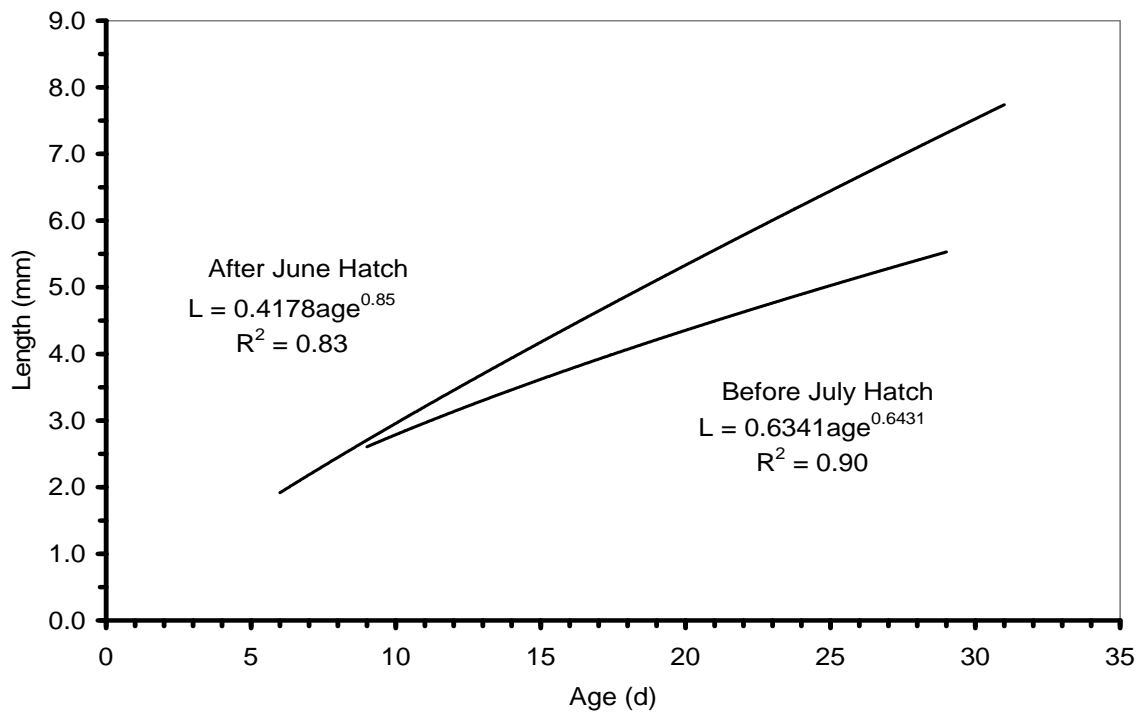


Figure 15. Spotfin croaker larval daily growth rate for individuals hatched before July 1, 2004 (n = 30) and after June 30, 2004 (n = 70). All larvae were collected offshore of Huntington Beach, California, between April 7 and August 28, 2004.

3.4.3. White Croaker

Larval white croaker daily growth ($n = 48$) was best described the function $L = -0.833 + 0.242 \text{ age}$ ($R^2 = 0.84$), indicating a slight reduction in growth rate with age during the larval period (Figure 16). Daily mortality was estimated at $M = 0.00978$. Stage-specific mortality was not examined due to the low sample size.

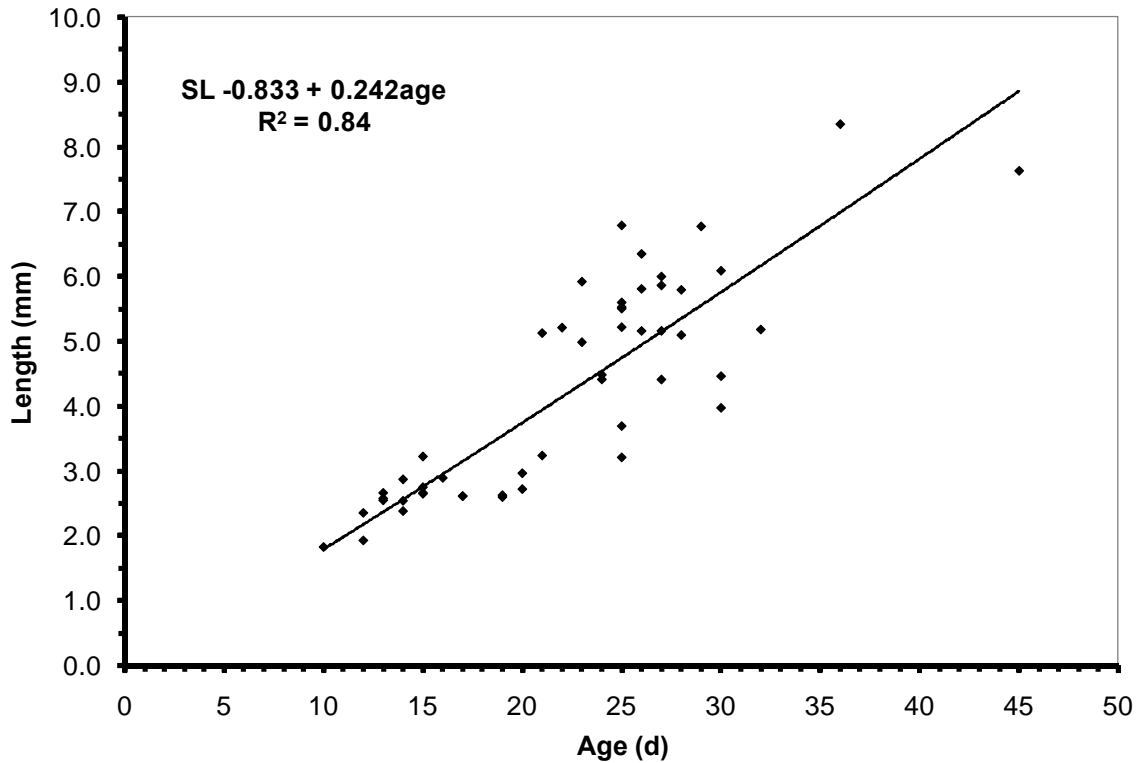


Figure 16. Larval white croaker daily growth ($n = 48$) for individuals collected offshore of Huntington Beach, California, from May through July, 2004.

4.0 Conclusions

4.1. Adult Age and Growth

Yellowfin croaker and queenfish exhibit growth patterns consistent with most Southern California nearshore fishes (Love et al. 1984; Allen et al. 1995; Love et al. 1996; Miller et al. 2008). Growth in both species was rapid through the early years before slowing. Annuli formation in each species was confirmed through otolith edge analysis, consistent with other sciaenids, such as weakfish (*Cynoscion regalis*) (Lowerre-Barbieri et al. 1994). Otolith increment analysis in both species indicated growth was fastest in the late summer and fall, beginning with the end of their summer reproductive period.

The maximum observed ages in this study were 15 years for yellowfin croaker and 12 years for queenfish. These ages were consistent with the similarly sized white croaker, which Love et al. (1984) aged to 12 years based on Southern California collections. These maximum ages were greatly reduced in comparison to the greater than 20-year lifespan for black croaker (Miller et al. 2008) and white seabass (*Atractoscion nobilis*) (Williams et al. 2007) based on otolith analysis. Joseph (1962) examined scales from spotfin croaker and California corbina (*Menticirrhus undulatus*) and found both species to live for fewer than 10 years. These maximum ages, however, may be underestimates in light of the more recent growth studies on Southern California sciaenids and the findings of increased accuracy of otolith analysis over scale analysis in Atlantic Ocean sciaenids (Lowerre-Barbieri et al. 1994).

Females in both yellowfin croaker and queenfish grew significantly faster than males. This was also consistent with white croaker (Love et al. 1984). This may be a reflection of the reproductive benefit, in the form of exponentially greater fecundity, afforded larger females (Helfman et al. 1997). This has been previously reported in queenfish (DeMartini and Fountain 1981) as well as in both spotfin croaker and yellowfin croaker during the fecundity elements of this study.

4.2. Adult Spawning Seasonality and Batch Fecundity

The observed spawning seasonality in yellowfin croaker was consistent with previous studies of Southern California sciaenids (Goldberg 1976; DeMartini and Fountain 1981; Goldberg 1981; Love et al. 1984; Miller et al. 2008). With the exception of white croaker, most California sciaenids typically reach their peak spawning activity during the spring and summer months, presumably brought about by seasonal increases in water temperature. Pondella et al. (2008) reported yellowfin croaker abundances were positively correlated with sea surface temperature. Furthermore, their analysis of yellowfin croaker entrapment rates at SONGS found abundances increasing in June to a peak in August, generally corresponding with the spawning seasonality documented by the current study. Lastly, they reported May collections were the second lowest, on average, which may explain the lack of available samples collected prior to June, despite sampling beginning in April.

Summer, serial spawning, as was suggested in this analysis, for yellowfin croaker was consistent with other local sciaenids such as queenfish and white croaker. Queenfish spawn from April through August based on histological analysis (Goldberg 1976). He further indicated the condition of the ovaries while in season was consistent with a species capable of multiple spawning events each year. DeMartini and Fountain (1981) later confirmed queenfish as a serial spawner with an estimated female spawning frequency of once every 7.4 days. Serial spawning was inferred from macroscopic analysis of white croaker ovaries, where the presence of hydrated eggs in 19% of the analyzed females indicated they spawned about once every five days (Love et al. 1984). Although the ovarian condition of the spawning females in the current study is indicative of serial spawning, no attempt was made to quantify the spawning periodicity or estimate the number of spawning events each female is capable of in a season. Therefore, total annual fecundity could not be empirically quantified.

Although spawning seasonality has been previously documented for several sciaenids, fecundity estimations were rare in the primary literature (DeMartini and Fountain 1981; Love et al. 1984). Yellowfin croaker and spotfin croaker batch fecundities were generally similar to published reports for weakfish (*Cynoscion regalis*) from the Chesapeake Bay and spotted sea trout (*Cynoscion nebulosus*) from the coast of Louisiana (Table 5). Batch fecundities for the four Southern California species analyzed generally reflect a maximum size:maximum batch fecundity proportional relationship, especially in comparison with larger species from outside the Southern California area. Red drum (*Sciaenops ocellatus*) and black drum (*Pogonias cromis*) collected from the Gulf of Mexico have substantially larger maximum sizes than the Southern California representatives with up to an eight-fold increase in maximum batch fecundity.

Table 5. Published batch fecundity range (reference) and maximum size for various North American sciaenids. Species common to Southern California are highlighted in bold.

Species	Fecundity range	Reference	Max. size
<i>Seriphus politus</i>	5,000 - 90,000	DeMartini and Fountain 1981	305 mm TL
<i>Genyonemus lineatus</i>	800 - 37,200	Love et al. 1984	410 mm TL
<i>Umbrina roncadore</i>	99,259 - 405,967	Current Study	560 mm TL
<i>Roncadore stearnsii</i>	35,169 - 640,703	Current Study	686 mm TL
<i>Cynoscion regalis</i>	75,289 - 517,845	Lowerre-Barbieri et al. 1996	980 mm TL
<i>Cynoscion nebulosus</i>	102,369 - 511,859	Nieland et al. 2002	1000 mm TL
<i>Sciaenops ocellatus</i>	160,000 - 3,270,000	Wilson and Nieland 1994	1550 mm TL
<i>Pogonias cromis</i>	510,000 - 2,420,000	Nieland and Wilson 1993	1700 mm TL

Source: www.fishbase.org

Unfortunately, no information on larval yellowfin croaker or spotfin croaker abundance was available in the primary literature to further illustrate both spawning seasonality and relative larval production (Barnett et al. 1984; Walker et al. 1987; McGowen 1993). Surprisingly, both species were absent in Walker et al. (1987), who conducted stratified sampling (surface, midwater, epibenthic) offshore of SONGS over a 29-month period from January 1978 through August 1980. Although yellowfin croaker was collected in

the summer months, they were not sufficiently abundant to meet the criteria for inclusion in the analysis (Walker, personal communication¹). More recent larval surveys conducted near Huntington Beach, California, from September 2003 through August 2004 recorded both species (MBC and Tenera 2005). The temporal distribution recorded offshore of Huntington Beach confirmed both the spawning seasonality for yellowfin croaker as well as the timing of peak batch fecundity for both species.

4.3. Larval Age and Growth

Two of the three sciaenids examined had larval growth rates indicating a gradual slowing of the growth rate with age, as the development of more advanced anatomical structures, such as the full fin complement, proceeded. White croaker larval growth was best described by a linear function suggesting a continued accretion of length with age over the size range of specimens used in this study. Unlike more streamlined species, such as anchovies (Family Engraulidae) and sardines (Family Clupeidae), croakers are more deep-bodied, which was most readily evaluated by examination of the length-weight relationships for taxa from each species. Miller et al. (2008) found the length-weight relationship to be best described by a linear function for several engraulid species, while the sciaenids all fit some form of an exponential relationship.

The formation of daily growth rings on sagittal otoliths, especially in sciaenids, has been repeatedly confirmed in both laboratory-reared and wild-caught larvae (Victor 1982; Victor and Brothers 1982; Jones 1986; Peters and McMichael 1987; Goshorn and Epifanio 1991; David et al. 1994). Sagittal otoliths, specifically, provided the most accurate age estimate in reared red drum (*Sciaenops ocellatus*) (David et al. 1994).

To date, no studies of the early life history of Southern California sciaenids have been published in the primary literature, thereby limiting the direct comparison of results from the current study to other local species. The growth rate for queenfish and spotfin croaker examined by the current study exhibited patterns consistent with wild-caught red drum (Peters and McMichael 1987). Laboratory-reared red drum, however, grew in a linear rather than the exponential pattern (David et al. 1994), similar to that observed in the white croaker specimens examined herein.

Seasonal growth differences in larval fish have been previously documented, especially among sciaenids (Jones 2002). Differences in cohort growth have been frequently linked to temperature (Houde and Zastrow 1993; Houde 1996; O'Connor et al. 2007) although not all marine species have been consistent with this pattern (Alvarez and Cotano 2005). Prey density and species composition have also been linked to growth rate, specifically as growth translates to survival such as in the match/mismatch hypothesis (Jones 2002) or Houde's stage duration hypothesis (Houde and Zastrow 1993; Houde 1996). Lastly, the size and vitality of the spawning female (maternal effects) have been linked to the overall growth and survival of marine larvae, mainly by determining the initial hatching

¹ H. J. Walker, Scripps Institution of Oceanography, San Diego, California.

size and corresponding prey niche breadth associated with the increased size, in relation to smaller members of the cohort (Chambers and Leggett 1996; Margulies et al. 2007). Of these, only temperature can be directly assumed to influence the differences observed in the seasonal growth of spotfin croaker, while no such differences were detected in queenfish and white croaker was not examined due to small sample size. Spotfin croaker exhibited significantly greater growth rates in the warmer summer months in comparison to the cooler winter and spring months. Prey density and composition were not examined in this study.

Daily mortality rates in larval marine fish can be influenced by a wide variety of factors, such as stage-specific growth, prey patchiness, water temperature, predator density, maternal influences, and dispersion patterns, among others (Lasker 1981; McGurk 1986; Houde 1987; Houde 1989; Goshorn and Epifanio 1991; MacKenzie and Leggett 1991; Houde and Zastrow 1993; Houde 1996; Helbig and Pepin 1998; Alvarez and Cotano 2005; O'Connor et al. 2007). Sampling sufficient size classes in their relative abundances has been of principal importance to the accurate estimation of daily mortality rates in larval fishes, especially given the high interannual variation in the controlling factors listed above (Helbig and Pepin 1998; Houde 2002). Helbig and Pepin (1998) further suggest the incorporation of dispersal into the general daily mortality estimation, especially for open coastal systems. This was largely based on the premise that due to the inherent patchiness of larval distributions, the declines in abundance with age can be the result of transport out of the sampling area into another area of equal or greater recruitment potential.

The importance of sampling all available size classes in their representative abundances lies in the accurate daily mortality estimation without inherent sampling bias (Houde 2002). Southern California sciaenids settle to the seafloor late in their larval stage (Barnett et al. 1984; Jahn and Lavenberg 1986), which requires sampling the epibenthic environment for the later stages. Barnett et al. (1984) confirmed older (based on morphological development) white croaker and queenfish were principally distributed near the bottom while younger stages were more cosmopolitan throughout the water column. Samples for this study were taken from those collected by oblique tow with a paired bongo net, which was designed to effectively sample the midwater. The addition of wheels to the bongo frame allowed it to also be used to sample the epibenthos (Brewer and Kleppel 1986). The lack of epibenthic sampling in the current study most likely accounted for the apparent increased mortality rate calculated for later stage larvae. In his summary of previous mortality estimation, Houde (2002) consistently found stage-specific mortality rates to decline with growth, rendering any values that contradict this as suspect. In the case of spotfin croaker especially, the late stage larval daily mortality was nearly twice that of the early stage larvae. This presumably can be mostly attributed to sampling bias, and possibly dispersion, rather than true mortality. While mortality estimates were presented for white croaker, queenfish, and spotfin croaker, their accuracy cannot be confirmed, especially for the later larval stages. The ontogenetic vertical distribution described by Barnett et al. (1984) suggests the early

stage mortality rates may accurately describe that stage, but the later stages, especially for spotfin croaker, is presumably incorrect.

5.0 Recommendations

Based on this study several recommendations can be made to further illustrate the life history parameters for California's marine fish to allow better impact assessment. These studies could dramatically increase one's knowledge of grossly understudied fish species. While not all species were commonly entrained or impinged, increases in knowledge of all nearshore fish species with the potential for entrainment or impingement provides powerful tools to better understand the ecological effect of once through cooling. Comparison of trends in frequently impinged and/or entrained species with those that were rarely recorded in power plant surveys could provide for a better understanding of the dynamics of the whole ecosystem involving once-through cooling, specifically if populations of affected and unaffected species were trending similarly or differently.

- **Early Life History Studies.**

- Identify a suite of species with similar reproductive seasonality for targeted sampling.
 - A suite species with similar reproductive seasonality will provide a greater taxonomic range with the understanding that not all species will be abundant in all years due to oceanographic conditions.
- New larval collections utilizing a vertically stratified design to more effectively sample the surface, midwater, and epibenthos.
- Sample all stations biweekly due to the inherent patchiness of larval fish and to document the seasonality of growth rates.
- Collect water quality parameters (temperature, dissolved oxygen, salinity, chlorophyll a concentrations) at each station during each survey.
- If sampling an open coast system:
 - Document prevailing current patterns to allow for calculation of dispersion in mortality estimation.
- Sample both within the Santa Monica Bay, offshore of the Los Angeles/Orange County area, and along the San Diego County coastline.
 - Additional sampling within bays and harbors in each of these areas.
 - Direct comparative studies in:
 - Alamitos and Anaheim Bays.
 - North and South San Diego Bay.
- Prospective species include: topsmelt (*Atherinops affinis*), jacksmelt (*Atherinopsis californiensis*), all croakers (to confirm mortality estimates),

California halibut (*Paralichthys californicus*), and Pacific pompano (*Peprilus simillimus*).

- All species used must be readily identifiable to the species level at all post-hatch stages.
 - Exclude goby A/C and combtooth blennies due to the difficulty in identification of early larval stages to species.
- **Adult life history studies.**
 - Adult age and growth, batch fecundity estimation, spawning seasonality, spawning frequency.
 - Collect samples from throughout the Southern California Bight.
 - Multiple sampling techniques to collect all post-recruitment size classes.
 - High sampling frequency at a select site for spawning frequency characterization.
 - Prospective species include: topsmelt, jacksmelt, California corbina (*Menticirrhus undulatus*), spotfin croaker, sargo (*Anisotremus davidsonii*), Pacific pompano, and select surfperch (Family Embiotocidae).

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7.0 Glossary

Fecundity	Potential reproductive capacity of an organism, measured by the number of gametes.
Ichthyoplankton	Eggs and larvae of fish found mainly in the upper 200 meters of the water column, also called the near-surface waters. The eggs are passive and drift in the ocean along with the water currents, feeding on smaller plankton. Initially most have no swimming but become active swimmers halfway through their development.
Otolith	A structure in the saccule or utricle of the inner ear, which are sensitive to horizontal and vertical acceleration. Class Osteichthyes have three pairs of otoliths – the sagittae (singular sagitta), lapilli (singular lapillus), and asterisci (singular asteriscus). The sagittae are the largest, found just behind the eyes and approximately level with them vertically. The lapilli and asterisci (smallest of the three) are located within the semicircular canals.
Hindcasting	Method used for testing a mathematical model. Closely estimated inputs for past events are entered into the model to see if the output matches the known results.
Otolith Annuli	Otoliths accrete layers of calcium carbonate as the fish grows, forming rings. These rings can be used to determine the age of the fish in days (typically using the sagittae).
Epibenthos	Organisms living on or immediately above the seafloor. Some are attached to the substrate, while others may be mobile.
Neuston	Organisms that float on top of the water or live just under the surface. Organisms made up of some species of fish, beetles, protozoans, bacteria and spiders.
Sciaenids	Family of fish (also called drums, croakers, or hardheads) which includes weakfish. Found in fresh and salt water, they are typically benthic carnivores, feeding on invertebrates and smaller fish.
Cohort	Fish in a stock that are born in the same year.